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A brief overview of the impact of avian influenza on animals

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ABSTRACT

Avian influenza (AI) virus, and the (HPAI)H5N1 subtype in particular, is a serious problem for many wild bird populations, where devastating losses have been reported. However, AI is not restricted to bird species. Here, a literature search was used to assess the range of animals infected by AI. This included reports in the scientific journals as well as news outlets. As can be seen, infection has been reported in commercial mammals such as cattle and mink where there is close animal-to-animal contact, as well as close contact with humans. Some domestic animals, such as cats, have been reported to be AI virus positive too, again where there is a possibility that conditions will be conducive to animal-to-human transmission. Many animals in the wild have been found to be infected with AI virus, and many of these, perhaps not surprisingly, are marine mammals. Mink-to-mink viral transmission has been suggested to have taken place, but most animals which have been infected have had close contact with birds, often handling or eating carcasses. There are also reports of humans becoming infected, for example, from cattle. Although this overview is intended to be neither comprehensive nor quantitative it is hoped that such information will aid in the management of AI, especially (HPAI)H5N1, in the future.

Contribution/Originality: This article gives an up-to-date overview of the range of animals which have been reported to be infection-positive for Avian influenza. This shows that the viral infection is not restricted to birds, but is found in many mammalian species.

1. INTRODUCTION

Avian influenza (AI) virus has been in circulation for many years. Originally referred to as "Fowl Plague" it was first described in northern Italy in 1878, and about twenty years later was found to be caused by a virus, which was further characterized in 1955 as a type A influenza virus [1]. Avian influenza (AI: often known as avian flu or bird flu) virus, especially the (HPAI)H5N1 subtype (clade 2.3.4.4b), is one of these. AI has led to devastating drops in bird populations, especially sea birds, such as reported by the BBC in February 2024 [2].

AI is caused by a virus which has two main types: Highly pathogenicity avian influenza [HPAI] and low pathogenicity avian influenza (LPAI) [3]. These groups are subdivided into haemagglutinin [H1–H16] and neuraminidase [N1–N9] subtypes. Most LPAI viruses cause a milder form of disease. HPAI viruses have H5 and H7 subtypes, and many of these subtypes have been found in infected birds. Probably the subtype of most concern is (HPAI)H5N1. Much has been written about bird outbreaks and possible bird infections, both in the scientific literature [4-6] and the popular media [2, 7-9] so this will not be considered in depth here. What is perhaps less well known is the evidence that AI viruses can infect a wide range of mammals, with differing symptoms. The fact that humans can become infected with the AI viruses is well-established, but remains of concern, and there is some discussion about H5N1 becoming the next pandemic subtype [10-12]. A recent British Broadcasting Corporation (BBC) article asks if the AI pandemic is inching towards humans [13].

Although there are other reviews covering this topic, such as that by Peacock, et al. [14] and others Consortium, et al. [15]; Graziosi, et al. [16] and Plaza, et al. [17] it seems timely to bring some examples of non-avian species being reported as infected with the AI virus together. Here a broad approach for a review is used, encompassing reports from science literature, but also more common media outlets such as news channels, as often these are looked at in isolation and by a wide range of readers. This is not a comprehensive report, but a brief overview to get an overall picture of what the present situation is like, and to highlight literature where a more in-depth discussion can be found if required.

2. MATERIALS AND METHODS

To obtain information for this overview a wide range of sources were used. These included reports found on the internet, and media outputs, such as Guardian newspaper (UK) and the BBC. Sci-entific literature was also sourced, primarily from Google Scholar [18] or National Library of Medicine Pubmed [19] and the original articles accessed and cited.

3. EVIDENCE OF A WIDE RANGE OF ANIMAL SPECIES BEING INFECTED WITH AI

There is certainly concern about where the next human viral pandemic will emerge from. SARS-Cov-2, which caused the COVID-19 pandemic, was thought to originate from bats, and the transmission to humans has been hotly debated, for example in work by Ridley and Brown [20] and the exact route will probably never be known. However, others have asked what we might consider as the next emergent zoonotic disease [21] and AI is a candidate.

In experimental animal models it has been clearly shown that some non-avian species can be infected with AI. H5N1 (HPAI) can cause upper respiratory tract infection in ferrets and cats [22] and ferrets have been used in cytokine studies Short, et al. [23]. Rhesus macaques have also been used, again for studying cytokine effects caused by AI [24]. Guinea pigs have been used for assessing the public health risk [25]. Belser [26] gave an update on the use of animal models, albeit back in 2009 [26] which included a discussion of the use of mice. Of course, more current reviews on the use of animals in influenza research are also available [e.g. Nguyen, et al. [27]].

With the media reporting that several animals are now being infected by AI virus, it is timely to look at this more deeply. In April 2024 the Guardian reported the first case of AI in a walrus [28] along with a wide range of birds, including penguins [29].

Here, we have looked across the literature and pulled out examples which highlight the widespread nature of AI virus. It clearly is not just found in avian species, as can be seen in Table 1.

Table 1. Examples of animals (Including humans) being reported positive for avian influenza vi-rus. Data was gathered until mid-August 2024.

Animal group	Animal type	Animal(s)	Country	Cause (If known)	Subtype (If known)	Ref.	Notes
Birds	Commercial	Poultry: Broiler chickens, turkeys	USA	-	A(H7N3)	USDA [30]	11 flocks, 8.8 M birds
		Poultry	Russia	-	A(H5N8)	Pyankova, et al. [31]	-
		Turkeys	USA	-	HPAI H5N1	CDC [32]	-
		Poultry	India	-	H5N1	World Organization for Animal Health [33]	-
Birds	Wild	Goose, duck, sanderling, eagle, crow, bufflehead, owl, cormorant, hawk, raven, vulture, ruddy turnstone, blackbird, pigeon, grackle, teal, pintail, swan, gull	USA	-	-	USDA [34]	-
		Penguins	South Georgia	-	-	BBC News [29]	-
		Mute swans (*Cygnus olor*)	Denmark	-	H5N1	World Organization for Animal Health (WOAH) [35]	Swans were dead
		Various (Non-poultry including wild birds)	Denmark	-	H5N8	World Organization for Animal Health [36]	-
		Various (Non-poultry including wild birds)	Canada	-	H5N5	World Organization for Animal Health [37]	-
		Great skuas	UK	-	H5N1	Guardian [38]	75% decline in population
		Gannets	UK	-	H5N1	Guardian [38]	25% decline in population
		Black-headed gulls, guillemots, kittiwakes, herring gulls, terns	UK	-	-	RSPB [39]	-
		Cranes	Hungary	-	-	RSPB [39]	Large outbreaks
		Swans	Romania	-	-	RSPB [39]	Large outbreaks
		Black-headed gulls	UK	-	-	British Trust for Ornithology [40]	10000 (4% UK population: 2023)
		Terns	UK	-	-	British Trust for Ornithology [40]	-
Birds	Domestic	8 cases in birds	Timor-Leste	-	H5N1	World Organization for Animal Health [41]	-

Mammal	Commercial	Dairy cows	USA	-	HPAI H5N1	CDC [32]	First cows reported (Kansas and Texas (March 2024)
		Cows (Cattle)	USA	-		USDA [42]	Across at least 10 states
		Mink	Spain	From wild waterfowl?	HPAI H5N1	CDC [32]	May have been mink-mink transmission
		Mink	Sweden	-	LPAI H10N4	CDC [32]	1984 (October)
		Mink	USA	From people (?)	A(H1N1)	CDC [32]	2019
		Goats	USA	-	H5N1	World Organization for Animal Health [43]	2024 (March)
		Foxes, mink, raccoon dogs	Finland	Not confirmed	-	UK Health Security Agency [44]	Near bird oubreak
		Big cat, lion, bobcat, bear, fox, coyote, fisher (*Pekania pennanti*), marten, otter, racoon, skunk, opossum, squirrel	USA	-	Includes H5N1	USDA [45]	-
		Seal, fox	UK	-	HPAI H5N8	CDC [32]	-
		Foxes, bears, skunks	Canada	-	H5N1	CDC [32]	-
Mammal	Wild	Fox	Netherlands	From birds?	HPAI H5N1	BBC News [29]	2021
		Fox	Estonia	-	-	CDC [32]	-
		Fox, otter, lynx, badger	Europe	-	HPAI H5	CDC [32]	-
		Raccoon dogs, foxes	Japan	-	HPAI H5	CDC [32]	-
		Polar bear	Arctic	-	HPAI A(H5N1)	CDC [32]	Animal died/first report from arctic animal (2023: December)
		Red fox	Sweden	-	H5N1	World Organization for Animal Health [46]	2023 (August)

		Red fox	Northern Ireland	-	HPAI H5N1	World Organization for Animal Health [47]	2023 (August)
		Red fox	Scotland	-	H5N1	World Organization for Animal Health [47]	-
		Cats	Poland	-	H5N1	World Organization for Animal Health [48]	-
		Cats	France, Italy	-	H5N1	UK Health Security Agency [44]	-
		Lion (*Panthera leo*)	Peru	-	H5N1	World Organization for Animal Health [48]	-
Mammal	Domestic	Cat	Thailand	Ate pigeon carcass	(HPAI) H5N1	Songserm, et al. [49]	-
		Cat	Germany	From wild birds?	H5N1	Klopfleisch, et al. [50]	-
		Cat	South Korea	Migratory birds that travelled from Japan and South Korea?	-	CIDRAP [51]	-
		Dogs	Italy	On poultry farm	-	UK Health Security Agency [44]	5 dogs infected
		Bush dog	UK	Contaminat-ed meat?	H5N1	CIDRAP [51]	-
		Bottle nose dolphin, seal,	USA	-	-	USDA [45]	-
		Walrus	Hopen Island (Svalbard)	-	-	The Guardian [28]	First such case April 2024
		Sea lions	Peru	-	HPAI H5N1	CDC [32]	-
Mammal	Marine	Sea lions	New England	-	H5N1	CDC [32]	-
		Seals	UK, Germany, Denmark	-	H7N7, H4N5, H4N6, H3N3, H10N7	CDC [32]	2021
		Seals	USA	-	HPAI H5N1	CDC [32]	10 animals

		Elephant seal, fur seal,	South polar region	-	HPAI A(H5N1)	CDC [32]	First from south polar region: 2023 (December)
		Grey seal, porpoise, dolphin	UK	-	HPAI H5N1 (H5Nx)	World Organization for Animal Health [47]	2023(March)
		Southern elephant seals (*Mirounga leonina*)/ 1 Antarctic fur seal (*Arctocephalus gazella*).	South Georgia Island	-	H5N1	World Organization for Animal Health [47]	-
		Seal lion (*Otaria flavescens*)- and dolphin (*Tursiops truncatus*)	Peru	-	H5N1	World Organization for Animal Health [48]	-
		Harbor seals (Phoca vitulina)	Denmark	Possibly from dead swans	HPAI H5N1	World Organization for Animal Health (WOAH) [35]	-
		Spiny porpoise (*Phocoena spinipinnis*) and Chilean dolphin (*Cephalorhynchus eutropia*).	Chile	-	H5N1	World Organization for Animal Health [48]	-
Mammal	Human	2 cases	USA	From poultry (2022), one from cattle (2024)	-	CDC [52]	-
		1 case	Russia	Poultry farmer- (December 2020)	A(H5N8)	Pyankova, et al. [31]	-
		Child with moderate illness	Hong Kong	Poultry (?) (2020)	LPAI H9N2	CDC [32]	-
		Child with mild illness	Senegal	Poultry (2019)	LPAI H9N2	CDC [32]	-
		Five cases	China	-	LPAI H9N2	CDC [32]	-
		Asymptomatic 80-year-old man	England	Ducks	HPAI H5N1	CDC [32]	-
			China	-	LPAI H3N8	CDC [32]	2022 (April)
		Seven cases	China	Poultry	HPAI H5N6	CDC [32]	2022
		Four cases	China	-	LPAI H9N2	CDC [32]	-
		Young child	Cambodia	-	LPAI H9N2	CDC [32]	-

		Child	Vietnam	Poultry	HPAI A(H5)	CDC [32]	-
		Four cases (Three children)	China	-	LPAI H9N2	CDC [32]	2022
		One case (died)	China	Poultry	HPAI H5N1	CDC [32]	2022
		Child	Laos	Poultry	HPAI H5N6	CDC [32]	2021
		One case (Died)	China	Poultry?	LPAI H10N3	CDC [32]	2021 (May)
		36 cases	China	-	HPAI H5N6	CDC [32]	During 2021 - 18 deaths
		24 cases	China	-	LPAI H9N2	CDC [32]	One death
		Four cases	China	Poultry	HPAI H5N6	CDC [32]	May-Sept 2022 - one death
		One case	China	Not known	LPAI H10N3	CDC [32]	2022(May)
		Four cases	China	-	LPAI H9N2	CDC [32]	One hospitalised
		Two cases (Asymptomatic)	Spain	Poultry workers	HPAI H5N1	CDC [32]	2022
		One case (Child)	Ecuador	Poultry	HPAI A(H5)	CDC [32]	2023 (January)
		Two cases (Asymptomatic)	Cambodia	-	HPAI H5N1	CDC [32]	One death
		One case	USA	-	HPAI) A(H5N1	CDC [32]	First case of cow-human transmission
		One case	USA	-	H5N1	Looi [53]	Farmer from cattle: State of Michigan

There are some general points which can be highlighted from the data. Firstly, it is obviously a global problem. In the UK, there are reports of major problems in birds in Scotland and Wales, for example, as reported by the BBC News [54] although on 30th May 2024 the UK government declared the country free of bird flu [55]. However, reports of animal infections span across USA, Russia, Japan, India, Thailand, South Korea etc. There are even reports from the polar regions, with elephant seals and fur seals being infected in the south [32] and polar bears being infected in the Arctic [32].

Secondly, there is a growing range of animals which are becoming infected. One of the groups which has reached prominence in the press is cattle [42]. This has been quite widespread, especially in the USA and it has been reported across at least ten States and 85 herds. Other commercial animals include goats [56] but perhaps more notably mink [32, 57]. Here worries may arise because of potential parallels with the prominence of mink infections during the COVID-19 pandemic [58]. During COVID-19, millions of mink in several countries were killed as they were found to be infected with SARS-CoV-2, mink-mink transmission was reported, and then perhaps more alarmingly there were suggestions of mink-human infection routes [59]. It has been thought that mink-mink AI viral transmission has already happened [32] as well as a farmer suspected of becoming infected from cattle [13]. A second case of a farmer being infected from a herd of cows was recently been reported [53] whilst in July 2024 it was reported that there were four dairy workers who had tested positive [60]. Infected cows may pass on the virus in their milk. The situation with AI virus and cattle was recently reviewed by Neumann and Kawaoka [61].

In USA, it has been reported that 24 cats contracted H5N1 on a single farm, and this was thought to be down to consumption of raw milk [62]. Half of these animals died. Cats more generally have been raised as a concern, with reports that in the USA at least 16 have contracted AI virus this year [63] presumably from eating infected wild birds.

As well as commercial animals which may be in contact with other animals, such as birds, but also in the close vicinity of humans, wild animals have been found to be infected. It is likely that these animals are becoming infected as they are in contact with, perhaps eating, infected carcasses. If a bird is frail because it is suffering, or if it had already died, then it becomes an easy target for other animals, many which are known to scavenge. Perhaps it should come as no surprise that foxes, bears, and coyotes are listed. Other species include lion, skunk, and otter. Domestic animals are being reported as being infected, especially cats [62, 63] and these may have become infected by eating carcasses, for example, one was reported as eating a dead pigeon, even though it would be assumed that such animals are well fed in their domestic environment. Cats were particularly infected with SARS-CoV-2 [64, 65] and although drawing parallels between the two diseases is fraught with issues due to the profound differences in the causative viruses, it is still quite concerning that companion animals are so susceptible to AI virus. Indeed, AI infection in cats is not trivial. In Poland, 47 cats were tested (including one *Caracal caracal*), with 29 being positive from 13 regions of the country. Cats had a range of symptoms, including bloody diarrhea, breathing problems and neurological issues. Eleven cats died [66]. And as stated above 16 were found to be positive in the USA this year [63].

Of prominence in the list given here are marine mammals (Table 1), no doubt because of their proximity to seabirds such as tern and gulls. Seals and walruses have already been mentioned here, but also listed are dolphins and porpoises. The reports are quite worldwide too, ranging from the UK and Denmark to USA, and then down to Peru, Chile, and the polar regions.

What can be seen from the results are several points worth noting. It is worldwide, it is not just avian species which have found to be infected, and, so far, contact with infected birds is often, but not always, the cause.

4. DISCUSSION

Birds have been the focus in discussions of AI spread and prevalent, although not all birds have the same morbidity [67, 68]. This is not the first time the matter of AI viral infection has been dis-cussed outside of bird species [69-71] and it is unlikely to be the last. Others are collating similar data, also on a global scale. One excellent source of data is from the Food and Agriculture Organization of the United Nations, which under a section on Animal Health, lists animals infected with H5Nx HPAI [72]. There are numerous bird species listed, as would be expected. These range across farmed animals including chickens, ducks, emu, and ostrich, as well as a wide range of wild birds. These include water birds such as ducks and geese, but also owls, hawks, robins, crows, and woodpeckers. Mammalian species which have been reported to be infected include a similar range of animals to that listed above, but also include wild boars, pika, and badgers. What is also telling about this list is that any new species identified as being positive since 2021 are written in red, and a glance at the list suggests about half of all the listings are so colored. This is an indication that either the viruses are spreading to more species quite dramatically, or that surveillance has significantly improved, or a combination of both.

One of the issues which is worth considering is of course why the virus has the ability to infect the cells of certain animals and not others. The molecular biology of the infection of cells with the AI virus is not covered here, but others have reviewed the area. For example, Wang, et al. [11] consider the epidemiology, virology and pathogenicity of human infections, with the view to gaining a better understanding of interspecies transmission of the virus. Charostad, et al. [73] discuss the structural biology and genetics of H5N1, and then go on to look at the immune response to the virus in humans.

The apparent prevalence of the AI virus across a range of mammalian species leads to some suggesting that we should at least raise awareness [74] with the BMJ asking if we should be worried "about a growing threat from "bird flu"", for example [75]. Therefore, it seems a timely point to bring some of the reports on how AI is affecting mammalian species into one place, and to discuss the range of what is happening around the world. This is particularly important as conservation work continues, and people interact with the natural environment, and animals within it, in a variety of ways [76].

Of importance here are the ramifications for human health. As highlighted in Table 1, humans around the world have been reported to be AI virus positive. Many of these so far are from China, Cambodia, Vietnam, Hong Kong and Laos, although there are other examples from USA, Spain, UK and Ecuador. Perhaps of particular concern is the suggestion that AI virus infected farmers who had close contact with their diseased cows [13, 53]. Therefore, there is no reason why any area of the world is safe and not likely to see future infections in humans. Such infections are often because people are in close contact with birds, usually poultry, which is an understandable route to become infected. Recently, the first death of a person with the H5N2 subtype of the virus was reported [74, 77].

This is far from a comprehensive review of the situation, but does highlight the breadth of the issue. Vaccines for AI are available, although in the UK it is stated that poultry and most captive birds must not be vaccinated, with zoo birds being able to be inoculated if they meet specific criteria [44]. What is unclear at this stage is how vaccination of animals involved in the food chain might be deemed appropriate, given it prevents serious disease rather than infection, thus might prove a risk within the food chain.

This short review may enable researchers, academics, and students to reflect on their activities. If walking along a beach and seeing a few dead gannets, is it appropriate to use them as a research sample or elements of them in an artwork [76]? Afterall, the European Centre for Disease Prevention and Control (ECDC) gives, "the general recommendation to not touch any sick or dead animals." [71]. They go on to say "There is no single vaccine against avian influenza. A specific vaccine is needed for each specific avian influenza strain," [as of Feb 2023]. Similar advice was given by the UK Health Security Agency, who advised that: "Members of the public should be discouraged from touching dead or sick animals." [44]. In twenty-three years leading up to 2019, 881 infections of

H5N1 were reported in humans, with a case fatality rate (CFR) rate of 52%, so this can be a serious disease. Of course, this is not the only review to suggest pandemic preparedness for AI [78] (and of course there is a general pandemic preparedness context [79]) but here are few there are things which could be done for the future. These may include:

- Better education of those who may come into contact with AI, especially if that contact may not be expected, such as on fieldtrips or simply being in the natural environment, or a farm setting. Worryingly, some people are seeking raw milk infected with H5N1, thinking that it will boost their immunity [80] so clearly correct dissemination of information is important;
- Further vigilance and surveying of the global situation. This is taking place by several organizations such as the CDC, but raw data needs to be fed into such databases;
- Further research into the animal-to-animal transmission of AI virus, and animal-to-human infection, as well as potentially human-to-animal infection with the virus;
- Can the susceptibility of animals to AI be predicted [78] and why do some animals get infected and not others [81]? This may give an idea of which species need to be targeted for surveillance and intervention, and as importantly, to know which animals can be ignored. Such attempts at predictions for the susceptibility to the SARS-CoV-2 virus appeared to have limited success, and several surprises were seen [59] but this should not prevent similar work being carried out with the AI virus;
- The consequences of the infection of specific animals need to be addressed in detail; not just from an economic or social point of view, but in the context of both human and animal disease control. Which animals are more likely to pass the disease on to humans? And which animals are likely to be infected by humans? Which animals (including humans) are likely to suffer more severe symptoms from the different subtypes? Might some animals act as a means of transmission of the virus? Might this be a source of a more contagious and/or virulent subtype, potentially with mammal to mammal and/or human-to-human transmission? Certainly, there is evidence that, for some viruses at least, infection of specific animal populations may enhance the viral mutation rate, making the emergence of such a dangerous subtype more likely [59]. Interestingly, it has been reported that the bovine HPAI H5N1 virus may have features which facilitates its infection and also transmission in mammals [82].
- What preparatory action should be taken in terms of the development and production (ultmately at scale, and of a vaccine for the specific subtype(s) necessary at the time, so not stockpiled) of AI virus vaccines, and a planned roll-out if required?
- How will the complexities of animal vaccination be navigated, both in relation to wild animals (including at risk populations), animals involved in the food chain (for meat, or eggs, for example), as well as pets. What will 'animal welfare' mean here for animals denied a vaccine, or subject to culling? How will this play out in terms of human need and human equity (such equity not being a feature of the SARS-CoV-2 pandemic) versus animal need? Will some animals be given vaccines before some humans (assuming that vaccine supply will be limited), and will this be on the basis of their perceived utility (such as farm animals, or endangered/valued species), or on the basis of their role and importance in disease transmission? If vaccination is not found to be effective in pre-venting disease but only decreasing symptomatic response, what will this mean for animals – based on the SARS-CoV-2 pandemic (and prior examples in the UK such a TB in cattle and badgers) the response may be one of culling, not vaccination. How will the response be affected by the relative severity of symptoms of the prevalent subtypes in a pandemic for humans and animals? These issues may fundamentally affect the 'landscape' for animals in the future, as well as the welfare of individual animals.

- What might be the impact on global food security? If vaccination is not 'the answer' (as some infected animals may pass into the food chain) then what impacts might there be on the availability of animal-based food material, and what specific enhanced biosecurity measures might be needed, at what cost, and to whom?
- In what ways should we be concerned about domestic animals, which after all, will have close contact with humans, so could infect, or be infected by, their humans. Cats have been shown to be susceptible to infection with AI virus (and high morbidity and mortality), for example (also seen with SARS-CoV-2); It is to be remembered that in the early stages of the COVID-19 pandemic, the UK Government did consider a cull of domestic cats [59].
- If an HPAI pandemic does arrive, with a subtype which has a high death rate for humans (say of the order of 50 percent), then what will be the impacts on animal welfare more broadly. We know during the COVID-19 pandemic that panic meant some animals were targeted [59] so it is not unreasonable to assume that pet abandonment, and the killing of 'suspected' wildlife, might also feature in human responses across the globe.

5. CONCLUSIONS

It is clear that Avian influenza viral infections are not restricted to birds and that several of the subtypes can cause infection in a wide range of mammal species, including humans. No reptiles, amphibians or fish have been found to be infected, but marine mammals are known to be AI virus positive. At the time of writing, one of the animals of most concern is cattle, partly as they are in the human food chain and also as they are in close contact with humans. Farmers have been reported to be infected, but to date no deaths of humans have been reported from this transmission route, with this subtype.

As with other zoonotic viruses, such as SARS-CoV-2, mutations are likely to take place in infected animals, and this will make it more likely that a wider range of vertebrate species could be infected, and it makes it more likely that a subtype will develop with the potential for human infection, and human to human transmission, and potentially high human morbidity and mortality, with potential for epidemic/pandemic.

It is hoped that this article will highlight some of the interesting emergent information about the global position with AI virus and animals, even though it is not intended to be a comprehensive review. Hopefully, the global pandemic preparedness initiatives will fully consider animal health, welfare and conservation aspects of AI infection. It is also to be hoped that current and future monitoring and vigilance, research and effective and timely mitigations will stop the spread and mutation of AI virus becoming the next human pandemic, with all the attendant animal and human welfare issues.

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